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Research Article

Prediction of Flexural Properties of Wood Material Reinforced with Various FRP Fabrics by Artificial Neural Networks[1]

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ABSTRACT

Recently, fiber reinforced polymer (FRP) applications have started to be used in the reinforcement of wooden structures, such as in the reinforcement of steel and reinforced concrete structures. It is necessary to strengthen the wooden structures for reasons such as removing the damages caused by external factors and earthquakes in time, increasing the load-bearing capacity of the structure by restoration, preventing early fatigue and breakages that may occur as a result of mistakes made in the design. The necessity to improve the repair and strengthening methods of the structures damaged as a result of the earthquake over time arises. In this study, the maximum load, displacement, flexural strength and modulus of elasticity of the wood material of Iroko and Ash tree species reinforced with 4 different FRP fabrics, namely carbon, glass, aramid and basalt, were determined by bending test. As a result of the experimental study, the maximum load, displacement, flexure strength and elasticity modulus values of the reinforced samples were estimated by artificial neural network (ANN). As a result, it was determined that the flexural properties of a wood material strengthened with FRP by using ANN can be predicted.

Keywords: *Wood Materials, FRP, Reinforcement, Artificial Neural Network, Iroko, Ash*

Çeşitli FRP Kumaşlarla Güçlendirilmiş Ahşap Malzemenin Eğilme Özelliklerinin Yapay Sinir Ağları ile Tahmini

ÖZ

Son zamanlarda çelik ve betonarme yapıların güçlendirilmesinde olduğu gibi ahşap yapıların güçlendirilmesinde de fiber takviyeli polimer (FRP) uygulamaları kullanılmaya başlanmıştır. Dış etkenlerin ve depremin neden olduğu hasarların zamanla giderilmesi, restorasyon ile yapının taşıma kapasitesinin artırılması, erken yorulma ve yapılan hatalar sonucu oluşabilecek kırılmaların önlenmesi gibi nedenlerle ahşap yapıların güçlendirilmesi gerekmektedir. Zamanla deprem sonucu hasar gören yapıların onarım ve güçlendirme yöntemlerinin iyileştirilmesi gerekliliği ortaya çıkmaktadır. Bu çalışmada, karbon, cam, aramid ve bazalt olmak üzere 4 farklı FRP kumaş ile güçlendirilmiş İroko ve Dişbudak ağaç türlerinin maksimum yükü, yer değiştirmesi, eğilme dayanımı ve elastisite modülü eğilme testi ile belirlenmiştir. Deneysel çalışma sonucunda, güçlendirilmiş numunelerin maksimum yük, yer değiştirme, eğilme dayanımı ve elastisite modülü değerleri yapay sinir ağları (YSA) ile tahmin edilmiştir. Sonuç olarak, YSA kullanılarak FRP ile güçlendirilmiş bir ahşap malzemenin eğilme özelliklerinin tahmin edilebileceği belirlenmiştir.

Anahtar Kelimeler: *Ahşap Malzeme, FRP, Güçlendirme, Yapay Sinir Ağları, Iroko, Dişbudak*

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I. INTRODUCTION

In addition to the superior properties of wood material, it also has some undesirable properties. These properties; Being destroyed by fungi and insects due to its organic structure, changing its dimensions depending on the humidity and temperature in the atmosphere due to its hygroscopic feature, and being a combustible material [1-3]. Therefore, the durability of wood in its natural state; in other words, the natural resistance time it shows against various environmental factors in the place of use cannot be long enough. Various biotic (vegetable, animal) and abiotic (physical, chemical, mechanical) pests that destroy the wood material have a great effect on this [4-8].

Wooden structures, which make up the majority of historical buildings, are exposed to wear caused by natural and artificial factors in the historical process. In order to transfer these structures, which are an important part of our cultural heritage, to future generations, wooden building elements need to be repaired and strengthened. In order for these restoration works to be of the desired quality, sufficient research should be done and restoration should be done with a scientific approach [9,10]. The fact that fiber reinforced polymers can be applied without spoiling the appearance of wood, in addition to their lightness, non-corrosion and flexibility, is a scientific fact revealing that FRPs should be preferred in solving the aforementioned problem [11,12]. Artificial neural networks (ANN), which is an artificial intelligence method, is a black box model that has been used frequently in recent years [13]. In recent years, various studies have been carried out in many areas for the use and development of artificial neural networks. As a result, the artificial neural networks literature has developed quite rapidly. Artificial neural networks have a wide range of applications [14,15]. Artificial neural networks are a system modeled on the basis of the human brain. It tries to solve problems that cannot be solved by classical methods with methods similar to the working system of the human brain [16]. In this study, flexural strength and modulus of elasticity values of Iroko (*Chlorophora excelsa*) and Ash (*Fraxinus excelsior*) beams reinforced with carbon, glass, basalt and aramid based FRP fabrics were estimated by artificial neural networks.

II. MATERIAL AND METHOD

A. PREPARATION OF SAMPLES AND FLEXURAL TESTS

In this study, ash (*Fraxinus excelsior*) and Iroko (*Chlorophora excelsa*) wood species, which is widely used in the production of wood composites and especially for structural purposes, is studied. The Iroko and Ash beam samples used in the study have been supplied from Antalya region. The wooden beams are manufactured from smooth, knot-free, flawless timber with dimensions of 20x20x360 mm. To determine the effect of fiber reinforced polymer type on the reinforcement of wood material, the sample fibers with carbon, aramid, basalt, and glass fibers polymers are used. The proper-ties of fiber reinforced polymer material are given in Table 1.

Table 1. *Technical properties of FRP fabric.*

Material Properties	Carbon	Aramid	Glass	Basalt
Weight (g/m^2)	300	300	300	200
Modulus of elasticity (GPa)	230	100	72	82
Tensile strength (N/mm^2)	4900	3300	3900	3200
Design Section Thickness (mm)	0.166	0.170	0.162	0.167

Before the beams are tested, all samples have been kept at temperature 20±2 ºC and relative humidity 65±5% conditions until they reached the same equilibrium humidity. Densities of wood materials were determined before the reinforcement application. Afterwards, the reinforcement process was carried out. The properties of the samples are given in Table 2.

Table 2. *The properties of the samples.*

Samples Code	N	FRP Type
I-FRP-C	15	Carbon
I-FRP-G	15	Glass
I-FRP-A	15	Aramid
I-FRP-B	15	Basalt
A-FRP-C	15	Carbon
A-FRP-G	15	Glass
A-FRP-A	15	Aramid
A-FRP-B	15	Basalt

In this study, at least two layers of wrapping are used for the strengthened samples with fiber-reinforced polymer fabrics, due to two layers of wrapping is proposed in the practical use of industry. Roll priming is performed to form a thin film layer (0.1 -0.2 mm) with an epoxy based primer developed for the MasterBrace® FRP (MasterBrace® P 3500) System. After the priming process, Developed Epoxy adhesive for MasterBrace® FRP (MasterBrace® SAT 4500) Fibres Polymer System is used. Epoxy adhesive is applied to the primed surfaces with a roller to achieve a thickness of 1 mm. As seen in Figure 1, the wrapping process of wooden beams with FRP composites has been performed in a U-shaped reinforcement in three regions of the beam.

Figure 1. *Wrapping process of wooden beams with FRP.*

After the epoxy adhesive is applied, fibers polymer fabrics cut in appropriate sizes are stretched in the direction of their fibers and adhered to the surface, immediately. Then, it is ensured that the epoxy is absorbed into the fabric and there is not any gap between it and the surface by pressing in the direction of the fibers of the fibrous polymer fabrics with a roller. After the first layer of adhesive is completed, the same operations have been repeated once again, the second layer is wrapped and the wrapping process is completed.

The wrapped beams are stored for 1 week before being subjected to the bending test. The flexural strength tests were performed on 20x20x360 mm specimens prepared according to TS 2474(2005).

B. MACHINE LEARNING METHODS USED FOR PREDICTIVE PURPOSES

Prediction of new data using mathematical relationship with existing data is machine learning [17]. This model consists of three different areas: supervised, unsupervised and reinforced learning [18]. supervised learning; It aims to detect correlations and obtain outputs using data [19]. Unsupervised learning aims to identify unknown structures from data [20]. Reinforced learning is a behavioral machine learning model similar to supervised learning, however, the algorithm is not trained using sample data [21]. Algorithms such as artificial neural networks, random forest algorithm, decision trees and support vector machine are used in machine learning [22]. Artificial neural networks were used in this study. ANN tries to train and predict the results of data not entered into the system [23].

C. CREATING THE DATA SET

After preparing 120 test materials, artificial neural networks were used to predict flexural properties. Artificial neural networks, which are among the widely used methods of artificial intelligence, are used in various fields [24]. 70% of the data used in the study was used for training of ANN and 30% for testing.

D. PERFORMANCE MEASUREMENT METRICS

It should be determined how successful the estimation methods used in the studies are. The Root Mean Square Error (RMSE) is frequently used in estimations and regression analysis. The R-Square (R^2) value shows the closeness of the regression line and the actual data values [25]. R^2 value varies between 0-1. Having this value close to 1 is important for the accuracy of the estimations. The Mean Absolute Error (MAE) is calculated as the mean of the absolute differences between the estimates and the target data.

III. RESULTS AND CONCLUSIONS

In this study, the flexural properties of the materials were estimated according to the wood density, FRP weight, FRP modulus of elasticity, tensile strength, design section thickness of FRP. Modulus of elasticity and flexural strength values of Ash and Iroko samples are given in Table 3.

Table 3. *Ash and Iroko samples test results.*

Sample Code	Modulus of elasticity (MPa)	Flexural strength (MPa)
I-FRP-C	126,16	12864
I-FRP-G	109,65	10981
I-FRP-A	119,99	12085
I-FRP-B	118,44	11956
A-FRP-C	125,38	12648
A-FRP-G	109,15	10762
A-FRP-A	119,64	12041
A-FRP-B	112,32	11950

In this study, artificial neural networks were used to estimate modulus of elasticity and flexural strength from wood density, FRP weight, FRP modulus of elasticity, tensile strength, and design section thickness of FRP. Statistical analysis results are given in Table 4.

Table 4. *Statistical analysis of prediction data of reinforced Iroko and Ash samples*.

Samples Code	RMSE	R^2	MAE
I-FRP-C	0,066635317	0,974765436	0,054791878
I-FRP-G	0,15227748	0,638888891	0,107777778
I-FRP-A	0,076122505	0,875195051	0,063914877
I-FRP-B	0,091841056	0,907869284	0,08350397
A-FRP-C	0,074889609	0,947781489	0,064212572
A-FRP-G	0,109652131	0,885863107	0,098525274
A-FRP-A	0,199627355	0,453113365	0,147715943
A-FRP-B	0,091161144	0,88244131	0,066579115

The flexural strength and modulus of elasticity values of reinforced ash and Iroko woods were estimated by considering various parameters. It was determined that the best estimation (R^2= 0.97) was made for Iroko beams reinforced with carbon-based fiber reinforced polymer. It was determined that the lowest estimation (R^2= 0.45) was made in ash beams reinforced with aramid based fiber reinforced polymer. In general, predictions were made with high accuracy in all samples that were strengthened.

Wooden materials could be destroyed over time and lose their function due to environmental conditions and the effect of various pests (fungi, insects, etc.). For this reason, wood material might lose its durability feature over time. In recent years, one of the methods used to increase the strength properties of these materials was reinforcement with fiber reinforced polymers. In this study, different lengths of reinforcement were applied with aramid based fiber reinforced polymers and the effects on the flexural strength, modulus of elasticity and load carrying capacity of wood material were investigated. Prepared test material properties were used for ANN to predict flexural properties of sample woods. Then, RMSE, R^2 and MAE values were calculated to show the efficiency of the ANN. Results showed that best value was obtained for Iroko beams reinforced with carbon-based fiber polymer with R^2= 0,97 and RMSE=0,066.

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